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MANUFACTURING CONSIDERATIONS IN THE SUPPORT OF LARGE GRP STORAGE VESSELS

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SUMMARY: Traditional glass reinforced plastic (GRP) storage vessel manufacture employs a mandrill, which is overlaid with fibres, mixed with resin. The structural properties of the material can be 'designed' by laying up the fibres in specific directions, or in specific forms e.g. chopped strand mat (CSM), to provide strength where appropriate. However, the support of these high integrity shells is often a secondary consideration and the manufacture and subsequent installation of the support systems is often overlooked until after the vessel has been delivered or arrived on site. Depending on the level of quality control applied during the manufacturing, the support system may be require to accommodate all manufacturing imperfections and therefore traditional design rules and methods may be rendered invalid.

The present work, on the optimisation of support systems for GRP vessels, has been undertaken using finite element methods running in parallel with a full experimental programme. During the experimental programme, significant deviations were observed in the longitudinal integrity of one of the vessels. Rather than scrap the vessel, investigations into the causes and consequences on the strain levels were undertaken. This paper therefore presents an insight into the manufacturing aspects of the support system interface for GRP vessels, and highlights the need for high quality control not only in the construction of the vessel shell but also in the design, construction and fixing of the support system.

KEYWORDS: GRP Storage Vessels, Support Systems, Manufacturing, Laminated Shells.

INTRODUCTION

Composite materials have characteristics that are often very different from more conventional engineering materials. As such, composite materials are being considered for a great number of industrial applications. An example of their use is the chemical industry, where, increasingly, pipes, tanks, pressure and storage vessels are being manufactured from fibre reinforced composites. Often it is the case that these materials offer direct replacement for traditional metallic materials. Care in design has to be taken in this case. A composite commonly used within the chemical industry is glass-fibre reinforced plastic (GRP) where both, weight and corrosion resistance, are influential factors. GRP composites are generally lightweight, comparatively being about a quarter the weight of steel and half the weight of aluminium.

GRP composites can be fabricated with near isotropic properties by suspending chopped strand mat (CSM) fibres in a suitable polymer resin matrix. Orthotropic properties are normal for a laminated construction when considering glass reinforcement produced in the form of directional filament winding (FW) or woven roving (WR). The properties of a composite material can thus be tailored to suit the intended application, by varying laminate thickness and the orientation and constituents of the individual laminae.

Generally, horizontal vessels are employed where there is a restriction in height or when there is a modest operating pressure. Their comparative lightweight means that they are ideal for storage at an elevated height or on offshore platforms, for example. Traditionally horizontal, cylindrical vessels are supported by two supports located symmetrically about the vessel mid-span. These systems have proved to be very efficient in the support of the traditional metallic vessels. For GRP vessels, twin-supports, symmetrically placed, are also preferred thus avoiding the transference of load, which occurs if differential settlement takes place in a multiple-support system. However, when the vessel is fabricated from GRP, the manufacturing processes often produce outer surface irregularities. The use of rigid saddles for the support of liquid-filled vessels can thus produce high values of radial interface pressure discretely as well as at the uppermost point of the saddle resulting in localised high strains in the vessel material, Ref. [1]. Peak strains that occur in the region of the saddle horn are compressive on the outer surface and tensile on the inner surface. If the magnitude of the inner surface tensile strain becomes excessive, local cracking may occur allowing liquid ingress to the glass resulting in premature failure by stress corrosion cracking. The support of the relatively flexible vessel on the rigid saddle results in the high strains locally at the top of the saddle. Therefore, at the design stage, the laminate properties of vessels should be tailored locally to account for the rigid supports, rather than the requirements for storage of the intended contents.

GRP VESSEL MANUFACTURE AND DESIGN FOR SUPPORT

General Considerations

In general, most modern GRP cylindrical storage vessels are constructed using a laminated system laid over a mandrill. The laminate consists of several layers of GRP with a mix of chop strand mat material (often sprayed on) and filament wound material. The filament wound material is applied automatically via a winding system, which allows a prescribed angle to be set, and the windings wrapped accordingly. Typical angles are 0°, 45°, 55°, 60° and 90°. windings. These angles can be easily controlled since the vessel is formed over a rotating mandrill.

The inner surface coat, known as the gel coat layer provides no structural resistance per say. However it acts as a chemical barrier to prevent liquid ingress to the fibre material. The inner surface dimensions are very accurate as the vessel is would directly to the mandrill. The outer surface dimensions, however can be quite rough. This imperfect surface arises due to the curing that takes place as the laminate is formed. In addition, reinforcing windings are present when the vessel is closed off by the introduction of the pre-formed dished ends. The cylindrical shell is locally thickened by the end reinforcement.

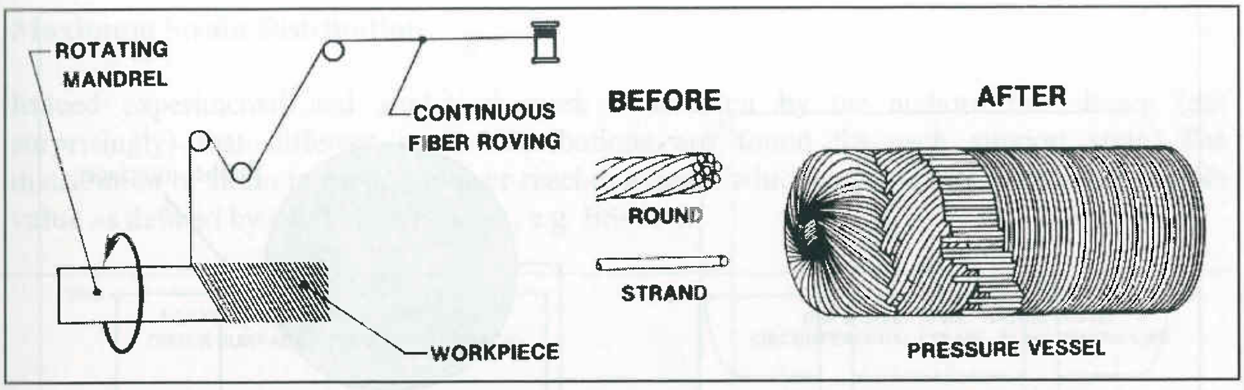


Fig. 1 Filament winding of a GRP storage vessel -schematic

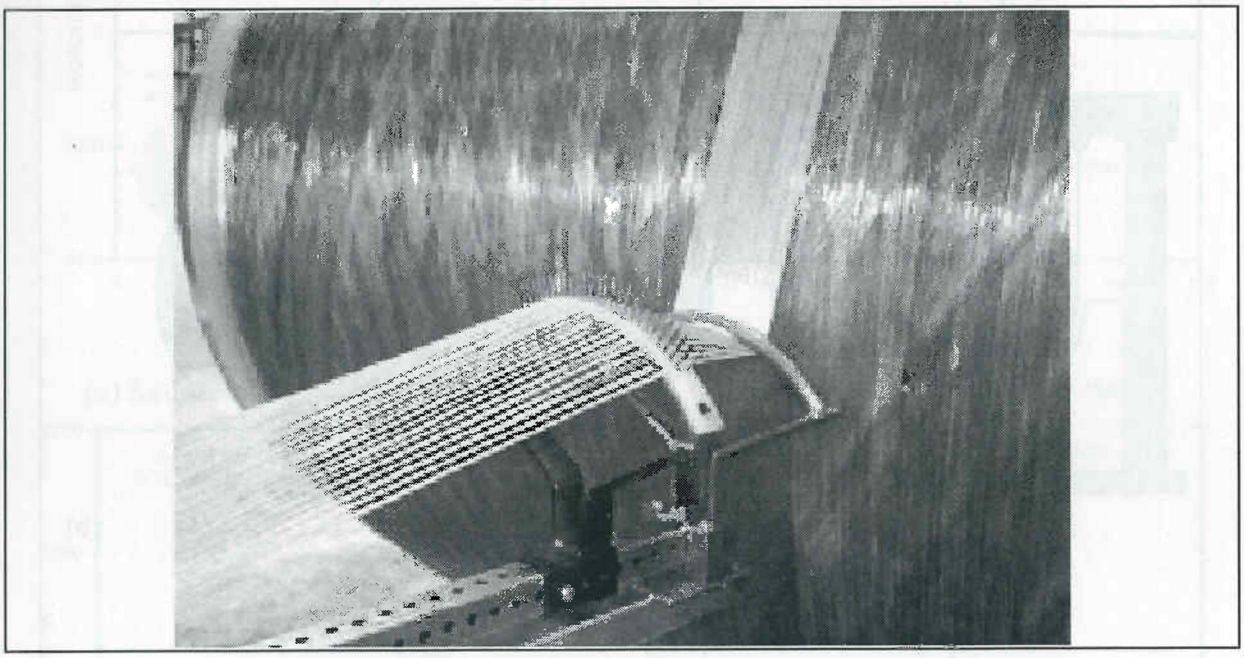


Fig. 2 Filament winding process showing outer surface variability

Support System Considerations

Twin saddle supports are the preferred support system for horizontal vessels, as this represents a statically determinate system. The main design consideration is the maximum strain, which is found at the saddle horn. This is due to the transition from support to free radial displacement that occurs at this position. Large radial interface forces are present which generate large bending strains in the vessel wall. In some cases, rubber is used at the vessel/saddle interface to take account of surface irregularities and to reduce the maximum strain levels, Fig. 3a. In general, saddle supported system in GRP vessel codes and standards, e.g. BS 4994 [2], are designed using similar methods to those for steel vessels, with a strain limitation being enforced as opposed to a stress based failure mechanism.

Alternative support systems are indicated in the above Standard and have been used. However little guidance is given in these documents. Previous work by the authors [3,4] has shown that ***flexible sling supports*** and ***longitudinal beam supports*** have been successfully used to support large GRP vessels as shown in Fig. 3b,c. The twin sling arrangement allows the vessel to freely expand when under load and is preferable when thinner vessels are required. A

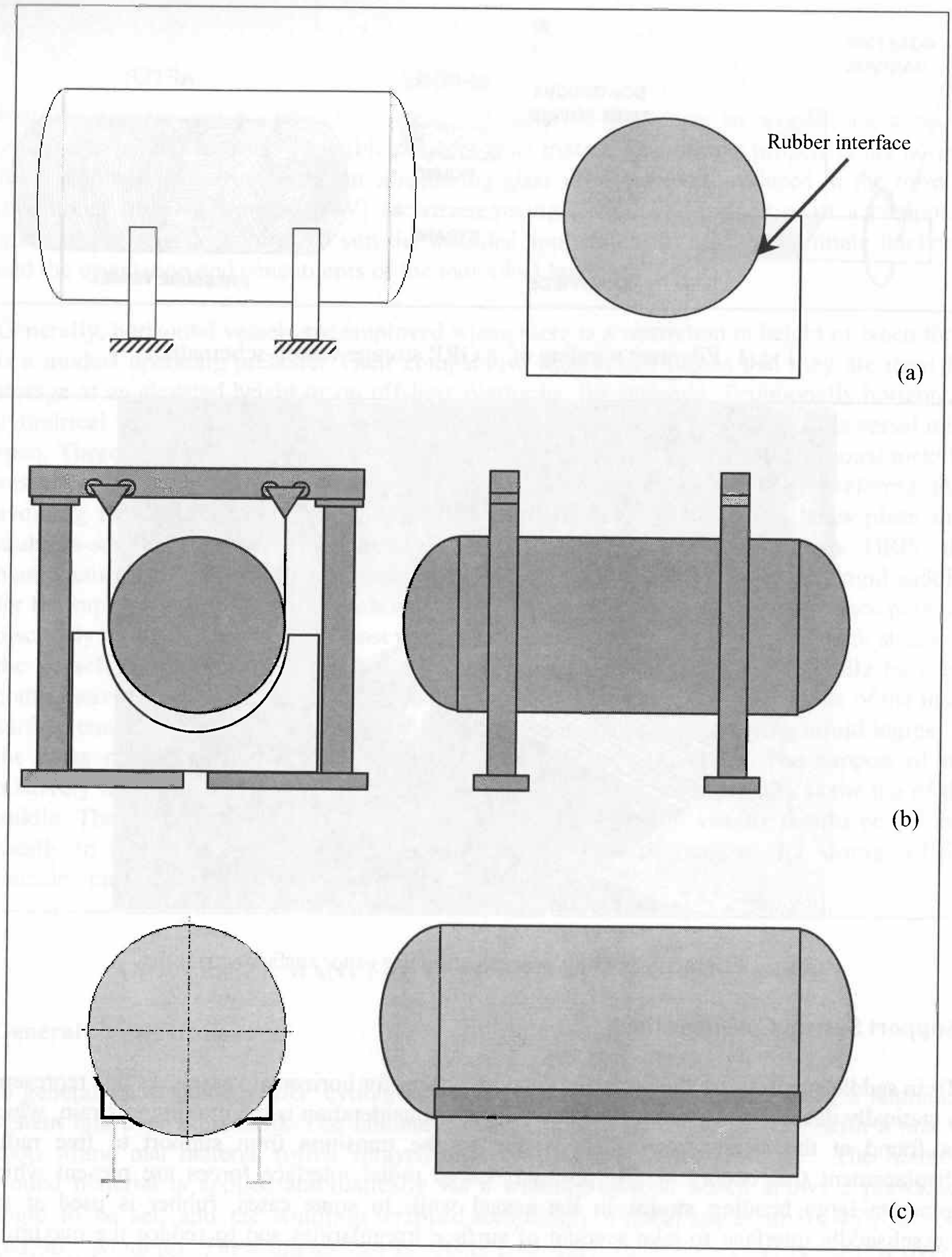
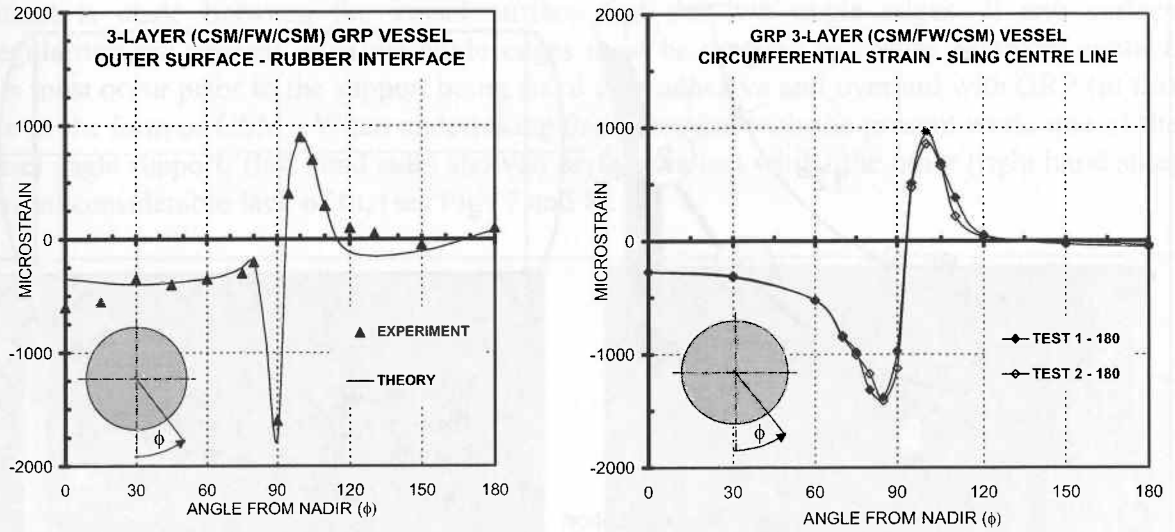


Fig. 3 Support arrangements a) Twin-saddle b) Sling-strap & c) Longitudinal beam

secondary support system with which to mount the sling is required. The use of flexible slings can eliminate peak strains, which arise when rigid saddles are employed. Longitudinal beam supports are preferred when the vessel is long, typically, length to radius ratio, $L/R>5$. The maximum strains when using beam supports are not located in the main vessel shell, as with the saddle and the sling, but rather occur in local concentrated zones at the beam ends.

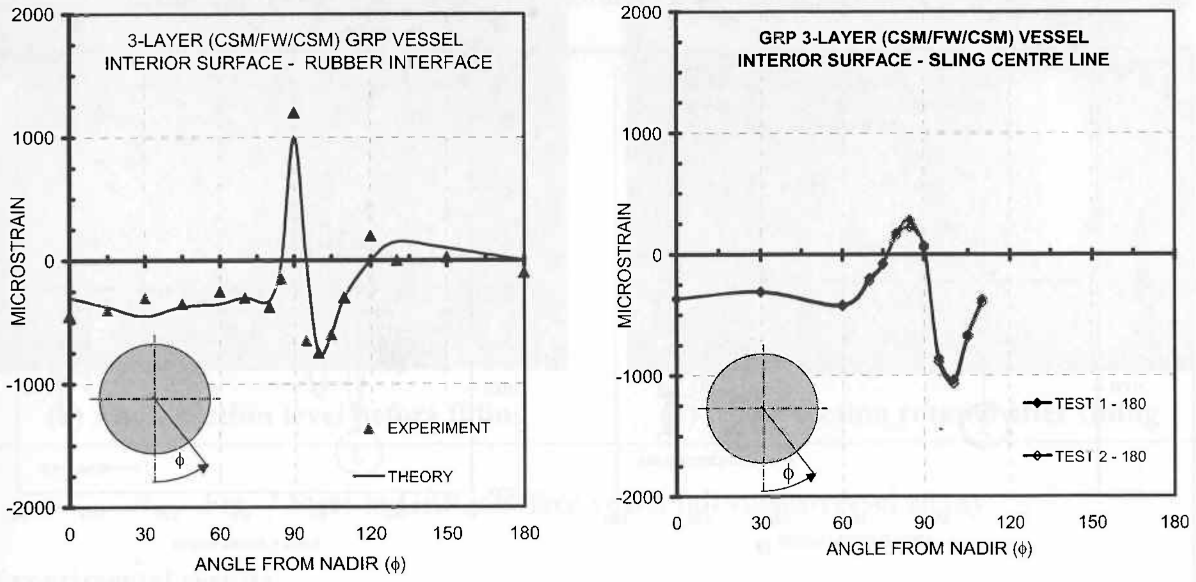
Maximum Strain Distribution

Indeed experimental and analytical work undertaken by the authors has shown (not surprisingly) that different strain distributions are found for each support style. The distribution of strain in each, however reaches a peak, which must be less than the allowable value as defined by international codes, e.g. BS4994.



(a) Saddle strains – outer surface

(b) Sling strains – outer surface



(c) Saddle strains – inner surface

(d) Sling strains – inner surface

Fig. 4 Experimental and analytical strain distribution for saddles and slings

The strain distributions for a three-layer system of a 2m-diameter vessel are shown in Fig.4. Both the saddle and sling support system distributions show peak strain rising in the vicinity of the horn or 'take-off' point, that is, where the vessel shell departs from the support system. At this location there is a tendency for local bending to occur and strains rise accordingly. In general, outer surface strains are higher, but are compressive in nature and therefore less dangerous. Inner surface strains, which can be more damaging, are generally lower.

LONGITUDINAL BEAM SUPPORT

The strain distribution for the longitudinal beam support system is quite different from the above. The beams were pultruded GRP sections. Experiments and analysis have shown there are several different locations that must be examined. Fig 5. details four sections along the vessel length and five particular circumferential strain gauge positions, which were investigated experimentally.

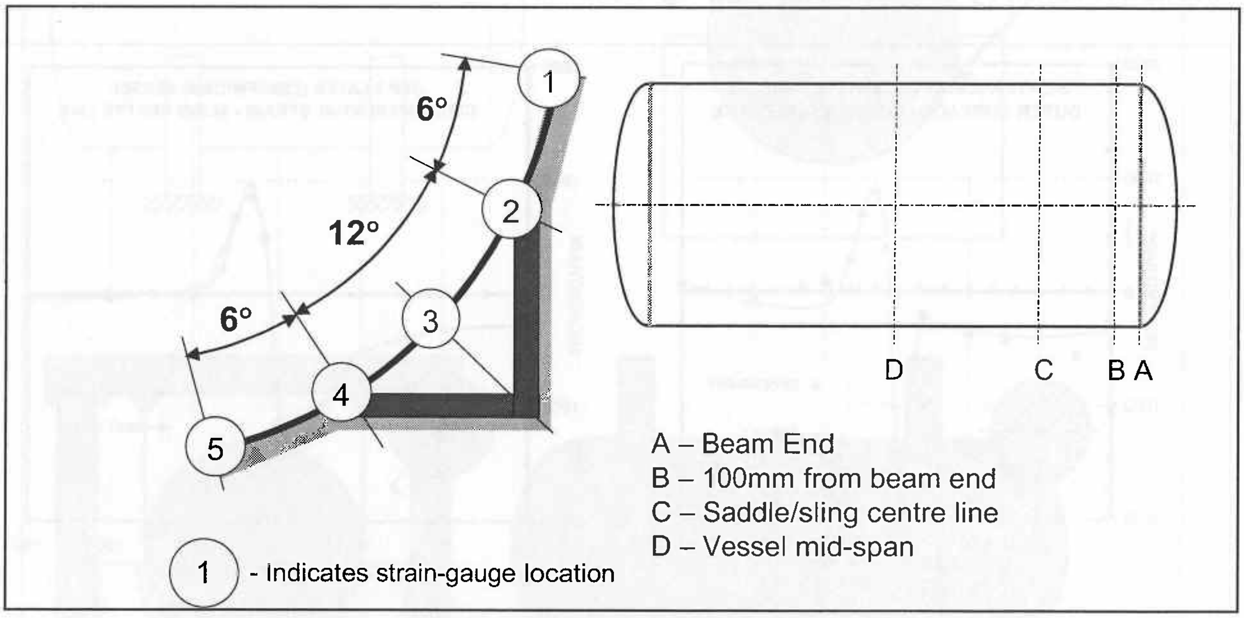
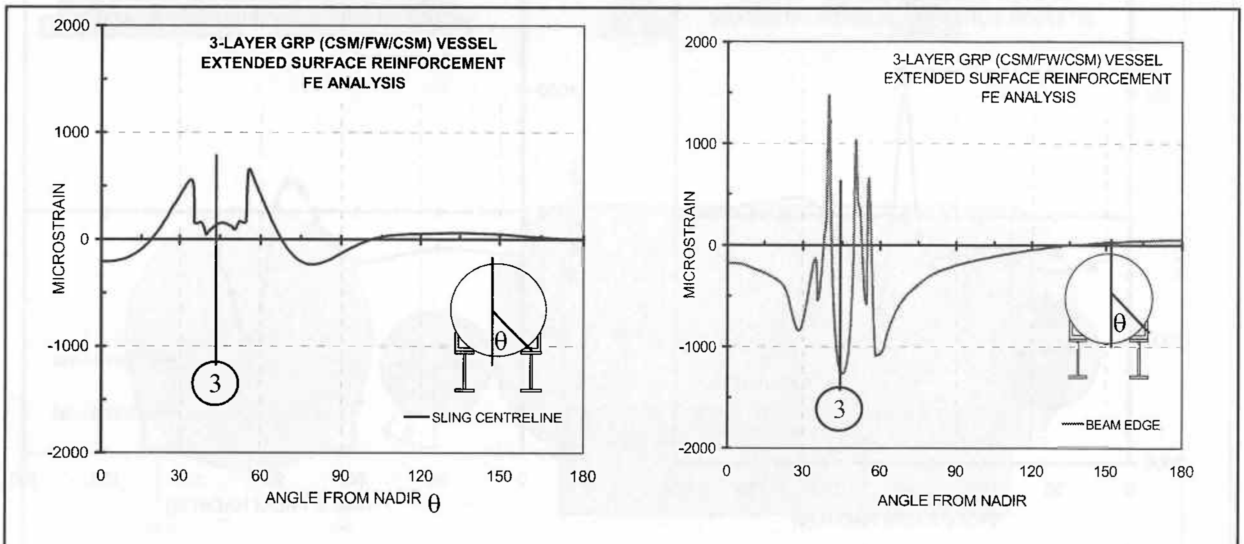


Fig. 5 Beam support strain locations from experimental programme



(a) Distribution at Plane C

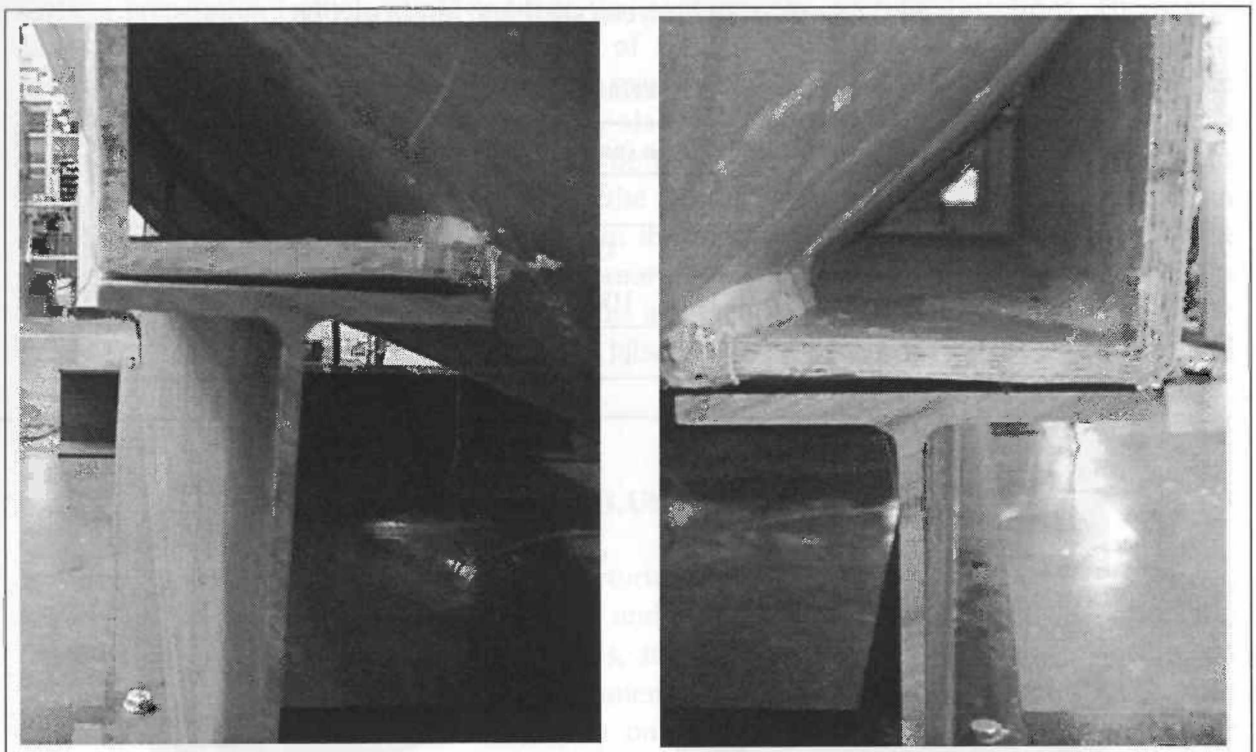
(b) Distribution at beam edge – Plane A

Fig. 6 Beam support strain distributions at mid section and beam edge

From Fig.6, the distribution of strain away from the beam edge is significantly lower than all other support styles. However, when considering the distribution at the beam edge, large peak strains are observed. It is noted that these distributions are obtained from the finite element studies and for the beam edge are erratic; this being due in part to the lack of elements at the vessel end. After consideration of the above graphs, the longitudinal beams were extended to wrap around the vessel end to see what reducing effect, if any, may be present.

Practical set up – subsidiary manufacturing considerations

When applying longitudinal beams to the outer surface of a GRP storage vessel, considerable time and effort is required to ensure good fit between the two mating surfaces. In fact, the contact is made between the vessel surface and the two angle edges. If any surface irregularities are present, then the angle edges must be profiled to ensure complete contact. This must occur prior to the support being fixed with adhesive and overlaid with GRP (in this case in the form of CSM). When undertaking this operation with the present work, one of the vessel angle support, (left hand side) showed perfect contact whilst the other (right hand side) showed considerable lack of fit, (see Figs 7 and 8).



(a) Angle section level before filling **(b) Angle section rotated after filling**

Fig. 7 Steel-to-GRP interface vessel full versus vessel empty

Experimental results

Table 1 shows the experimental results for two tests. The good profile, (LHS), shows lower strains than the poor fit profile (RHS), except for position C. However, strain readings were large at profile A for both sides. This coincided with the end of the beam. A practical manufacturing modification was introduced in the form of an extended beam, wrapping around the vessel end. This was in the form of a CSM hand laid-up over a polypropylene former. The details are indicated in Fig. 9. The tests and analysis were then repeated. From a practical standpoint, the experimental vessel beam was now in two parts, albeit both fully laminated to the vessel. However, ideally in a practical application, beams should be completely integral prior to fitting to avoid unnecessary flexibility and discontinuity of load transfer.

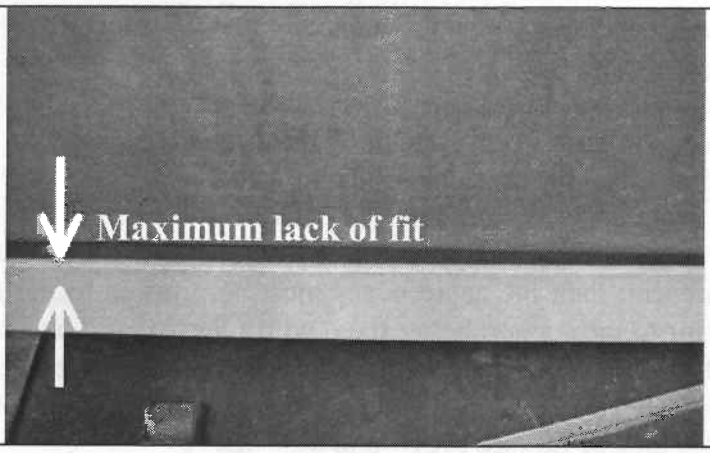


Fig. 8 Lack of fit between shell and angle section

Table 1. Beam support with rubber interface - peak strain distribution - experiments

Test No.	Maximum tensile strain (με) at indicated circumferential position							
	Good Profile (LHS)				Bad Profile (RHS)			
	A	B	C	D	A	B	C	D
1	985	1095	981	1005	1737	1450	596	1191
2	993	1077	890	1155	1756	1470	595	1175

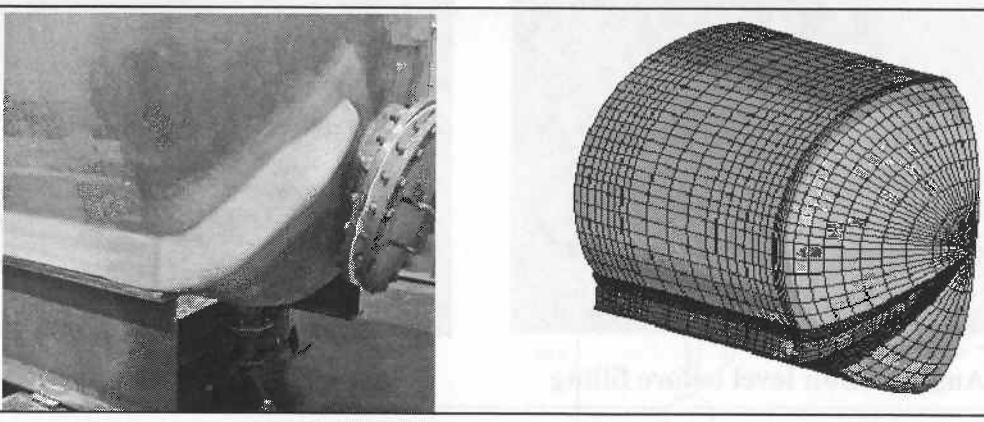


Fig. 9 Experimental and finite element representation [5] of wraparound beam

At a glance it is evident, from Table 2, that the maximum strains from the wraparound test actually increased at locations A, B and D, compared with the previous tests, Table 1. Ignoring the magnitude of strain but comparing its distribution produces a similar trend to Table 1. Considering firstly the LHS, the maximum strain occurs at profile B 100mm from the beam edge with a magnitude of around 1510με, an increase of approximately 50% compared with the rubber-to-GRP tests. Similarly, the maximum strain at the RHS increased this time to a value of almost 2200με, which is in excess of the BS4994 design limit of 2000με. However, the increase in strain is localised in the region occupied by the edge of the beam, showing an apparent reduction at profiles C and D for the LHS at profile C. The peak strain is reduced from 981με to a value of 288με and at profile D, the vessel mid-span the reduction is from 1005με to 750με.

Table 2. Wraparound extension – peak strain distribution- experiments

LONGITUDINAL BEAM SUPPORT - WRAPAROUND								
Test No.	**Maximum tensile strain (με) at indicated circumferential position**							
	Profile (LHS)				**Profile (RHS)**			
	A	B	C	D	A	B	C	D
1	1276	1509	288	750	2167	1603	339	830
2	1265	1516	283	746	2144	1591	345	842

A possible reason for the apparent increase in strain at profiles A and B may be accounted for by insufficient bonding between the angle-section and the wraparound laminate due to the surface preparation (which would indicate the necessity for careful fabrication). The angle-section thickness was reduced by removal of GRP material over a length of 150mm to accommodate the wraparound laminate. The manufacturing process applied to extending the angle-section form around the vessel end may also thus account for the increase in strain. As a result, it is considered that the load may not be fully transferred along the vessel length into the end and local reduction in thickness of the angle-section near the vessel end incurs an increase in magnitude of strain locally. From the finite element results, which employed a fully connected integral beam, a reduction of more than 25% in the maximum measured strain results when the wraparound was applied. This assumed that the wraparound extended to the crown at the end. Reductions in strain were also observed even with a modest wraparound applied.

CONCLUSIONS

An investigation of the design and manufacturing aspects of large cylindrical GRP storage vessels and their support systems has been undertaken. Traditional design is based on the vessels being supported on rigid twin saddles, and ensuring maximum strains do not exceed 2000με. In addition, because of the filament winding process, manufacturers ensure dimensional accuracy on the inside surface only. Attaching support systems to the outer surface requires consideration of the irregularities present.

Saddles with rubber interfaces are well able to cope with surface irregularities, as are flexible slings, which also deal well with thin large displacement vessels. Longitudinal beam supports require special consideration, as care must be taken to ensure good fit between the angle edges and the vessel surface. Hand profile is usually required. If extended beams with end wraparounds are employed, these must be continuous and well attached. If not, large localised strains may result and the wraparound extensions may be more detrimental than beneficial.

ACKNOWLEDGEMENTS

The authors wish to note the major contribution made by Emeritus Professor Alwyn S Tooth to this on-going research topic. Professor Tooth passed away during the completion of this work.

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